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A Proposed Information Architecture for Telehealth System Interoperability

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Abstract

Telemedicine technology is rapidly evolving. Whereas early telemedicine consultations relied primarily on video conferencing, consultations today may utilize video conferencing, medical peripherals, store-and-forward capabilities, electronic patient record management software, and/or a host of other emerging technologies. These remote care systems rely increasingly on distributed, collaborative information technology during the care delivery process, in its many forms. While these leading-edge systems are bellwethers for highly advanced telemedicine, the remote care market today is still immature. Most telemedicine systems are custom-designed and do not interoperate with other commercial offerings. Users are limited to a set of functionality that a single vendor provides and must often pay high prices to obtain this functionality, since vendors in this marketplace must deliver entire systems in order to compete. Besides increasing corporate research and development costs, this inhibits the ability of the user to make intelligent purchasing decisions regarding best-of-breed technologies.

We propose a secure, object-oriented information architecture for telemedicine systems that promotes 'plug-and-play' interaction between system components through standardized interfaces, communication protocols, messaging formats, and data definitions. In this architecture, each component functions as a black box, and components plug together in a "lego-like" fashion to achieve the desired device or system functionality. The architecture will support various ongoing standards work in the medical device arena.

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Table of Contents

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Introduction

The United States health care industry is experiencing a dramatic paradigm shift due to the convergence of several technology areas. Increasingly-capable telehealth systems and the internet are not only moving the point of care closer to the patient, but the patient can now assume a more active role in his or her own care. These technologies, coupled with (1) the migration of the health care industry to electronic patient records and (2) the emergence of a growing number of enabling health care technologies (e.g., novel biosensors, intelligent software agents, and wearable devices), demonstrate unprecedented potential for effectively delivering highly automated, patient-centric health care while at the same time reducing the cost of care [1].

Whereas early telemedicine consultations relied primarily on video conferencing, consultations today may utilize video conferencing, medical peripherals, store-and-forward capabilities, electronic patient record management software, and/or a host of other emerging technologies (see Figure 1). While these leading-edge systems are bellwethers for highly advanced telemedicine, the remote care market today is still immature. Most commercial systems are custom-designed, “stovepipe” systems that do not interoperate with other commercial offerings. Users are limited to a set of functionality that a single vendor provides and must often pay high prices to obtain this functionality, since vendors in this marketplace must deliver entire systems in order to compete. Besides increasing corporate research and development costs, this inhibits the ability of the user to make intelligent purchasing decisions regarding best-of-breed technologies.

This paper proposes a reference architecture for plug-and-play telemedicine devices and systems, presents high-level technical details about the initial implementation of the architecture, and denotes the types of component technologies and standards that the system may utilize.

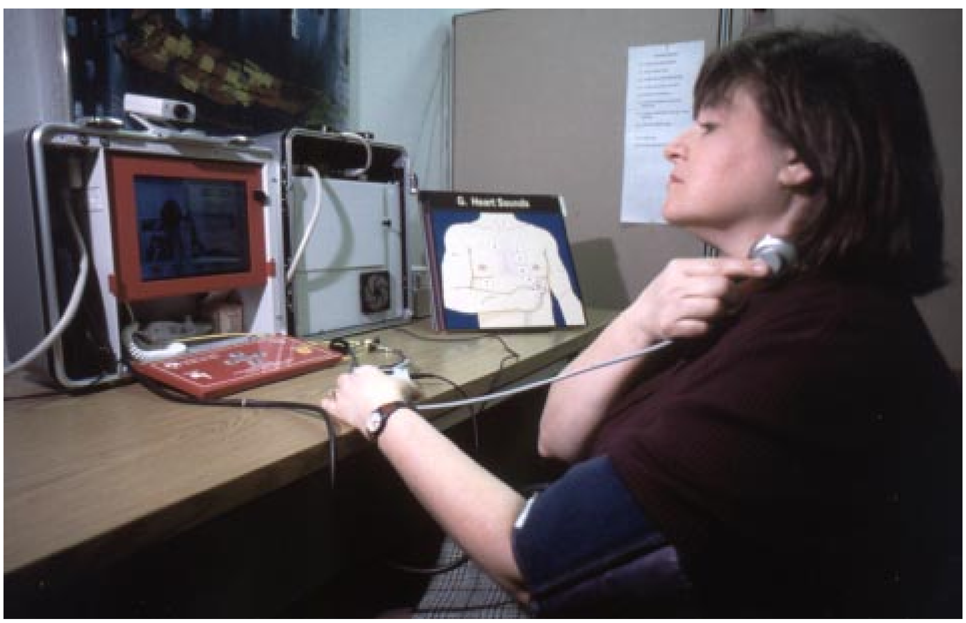

Figure 1. The patient station in a state-of-the-art, desktop telemedicine system. Photograph courtesy Richard N. Re, M.D. and Marie A. Krousel-Wood, M.D., Alton Ochsner Medical Foundation, New Orleans, LA.

Proposed Telemedicine Device Architecture: Overview

The following is a general overview of a proposed object-oriented information architecture for telemedicine devices that promotes 'plug-and-play' interaction between system components through standardized interfaces, communication protocols, messaging formats, and data definitions. The general functional areas of the architecture are described first, followed by a high-level description of the component interactions.

Areas of Functionality

In general, telemedicine devices provide users with seven sets of services, as shown in Figure 2. Note that every device does not provide all available services.

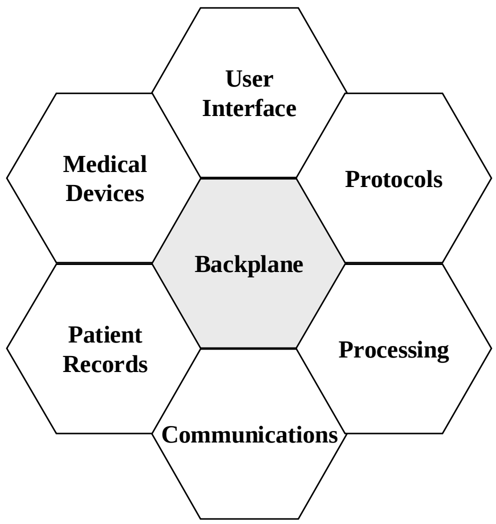

Figure 2. General types of services represented in the proposed telemedicine device architecture.

The following items describe these architectural services:

- The ***USER INTERFACE*** service represents hardware and software with which the user interacts, including mechanisms that support telemedicine device control (e.g., buttons and lights on the front panel of an instrument) and person-to-person interactions.
- The ***MEDICAL DEVICES*** service represents mechanisms for acquiring patient data, delivering therapy to a patient, or analyzing specimens collected from a patient.
- The ***PATIENT RECORDS*** service represents a device's ability to store and retrieve information that the device has collected about a patient.
- The ***PROCESSING*** service consists of specialized routines to manipulate data. Examples of this include statistical routines to analyze trends in data sets, filtering routines to manipulate waveforms and images, and "intelligent agents" that aid in diagnosis and care planning.
- The ***COMMUNICATIONS*** service represents (1) mechanisms a telemedicine device uses to communicate with other devices and (2) the services that support these communications (e.g., address books that contain email addresses, or directories that indicate where to find specific services).
- The ***PROTOCOLS*** service constitutes the brain of a telemedicine device. The "programs" or "scripts" in this service area accomplish specific medical objectives by utilizing resources acquired from the other services. A simple protocol might, for example, direct a medical instrument to take a reading, tell the patient record to store the reading, and tell the user interface to display the reading. Protocols can deliver sophisticated functionality through command nesting.
- Finally, the ***BACKPLANE*** service represents mechanisms that tie the other six services together. It provides intra-device communications, as well as profile information needed for device "self-

awareness." This self-awareness is essential to creating devices that work with one another in a plug-and-play fashion.

System Configurations

A significant advantage of this device-partitioning scheme is that a common set of building blocks can create a number of different systems (see Figure 3 below). Given this partitioning and a sufficiently capable communications infrastructure, one can create telemedicine "devices" that are more virtual than physical. One model for this is Intel's "Anywhere in the Home" Initiative, which seeks to "…unleash the power of your PC throughout your home, throughout your day, [by means of] a seamless network of new and existing intelligent devices in your home that help light the way to a new and better quality of life." [2] In this vision, a collection of capable, interconnected resources distributed throughout the home replaces the personal computer. While Intel's current vision is limited to work and entertainment in the home, it applies equally well to medical systems such as telehealth units. Tomorrow's telehealth systems will, in a similar manner, incorporate inexpensive commercial-off-the-shelf components in their distributed designs. These components will be dispersed throughout the patient's environment and be accessible when necessary to other parties (e.g., the family doctor). Although scattered across a network, these components will still act as a single system that acquires state-of-health information about a patient. Assuming the right protections are in place, an outside party will not be able to tell whether a device is a confederation of components or a monolithic unit.

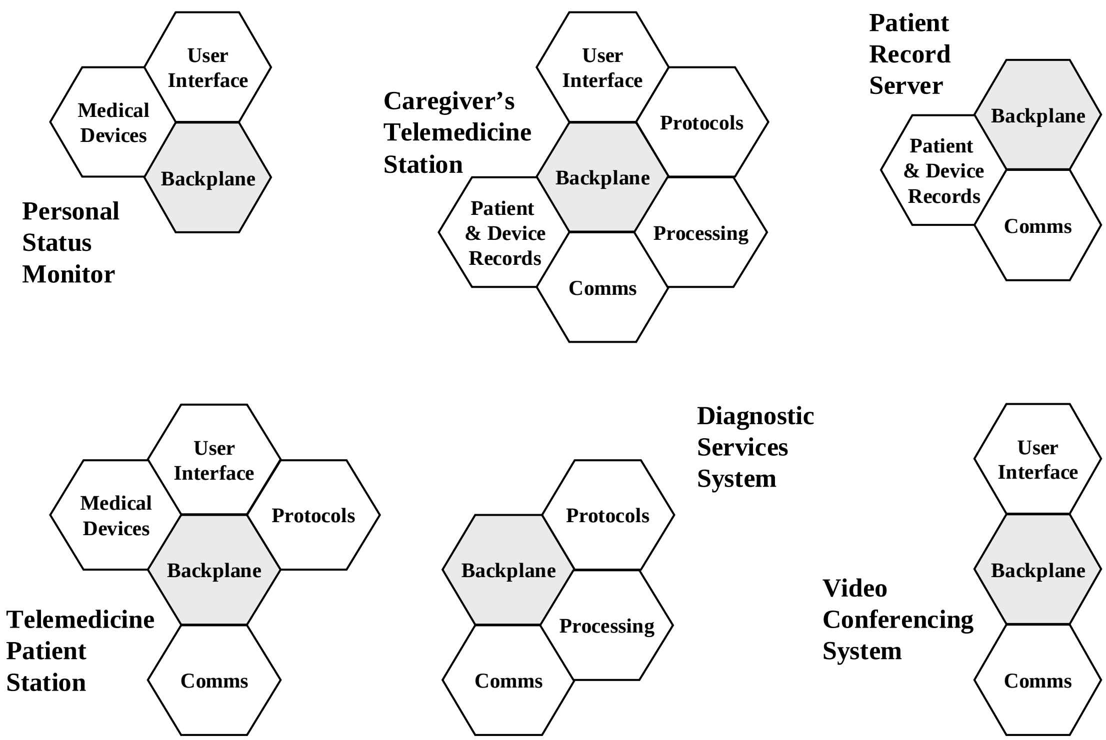

Figure 3. Telemedicine systems created from a common set of architectural building blocks.

Proposed Telemedicine Device Architecture: Component Descriptions

In this architecture, each component functions as a black box, and components plug together in a "lego-like" fashion to achieve the desired device or system functionality. The functional superset represented in these components is controlled by predefined protocols that can be chosen by the user to execute a certain procedure, or set of tasks. Systems based on this architecture will be dynamic because users will be able to swap functionality in a hot-pluggable fashion. A depiction of the general component interactions within this architecture is shown in Figure 4. The following sections define terms relevant to this interaction diagram and denote the types of operations that are performed by these components.

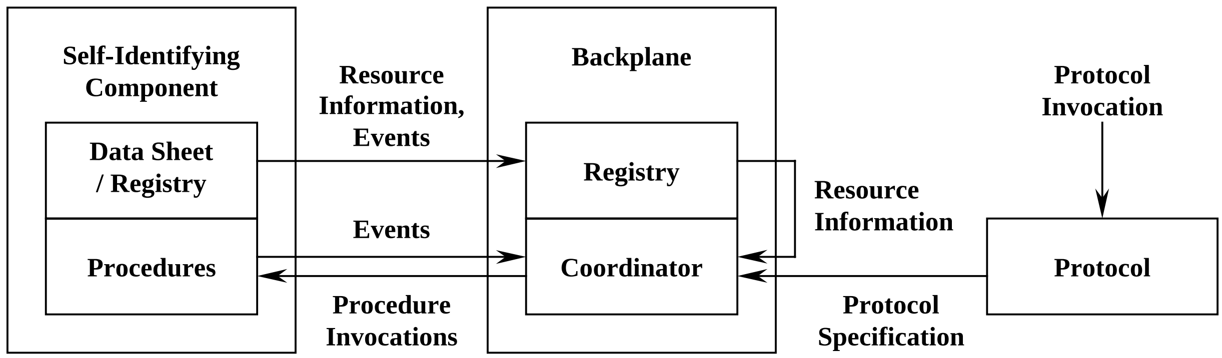

Figure 4. Depiction of the general component interactions in the proposed architecture.

Definitions

Protocol

A protocol is a persistent collection of resources, connections, and events necessary to accomplish a medical task. Here, a resource can be a medical device, a user interface control, a communication connection, a data filter, or even another protocol. With the exception of the backplane, each architectural component can supply resources specified in a protocol. In order for resources to be useful, a coordinator object (described below) must first call the methods of each resource to specify the connections between these resources. In this scheme, events are activities denoted in an ordered protocol, where an event may equate to a procedure invocation that is sent to a device object. Note that a protocol can request other protocols as resources in a recursive manner. Protocol command syntax will be delimited by a Protocol Definition Language (see the section below).

Procedure

A procedure is a device-specific set of events or commands. Ideally, device vendors would supply procedures in order to utilize custom device features inaccessible to standard architectural resources.

Protocol Definition Language

A Protocol Definition Language (PDL) delimits the syntax and functionality of component protocols. Although the PDL was initially targeted as a custom language to meet the requirements of this architecture, technologies such as XML appear to provide a better solution. Not only can document types specify the semantic concepts of resources, connections and events, but parsers for this type of capability are freely available, avoiding development work required to support the needs of "yet another compiler."

Key Architectural Concepts

The three key concepts of the proposed telemedicine device architecture are (1) components that utilize registries, (2) self-identifying components, and (3) coordinators that execute protocols. Each component registry is a repository that can gain, lose, and utilize resources during device operation. Objects that embody resources must first advertise their resource capabilities and requirements to the appropriate component registries. The relevant coordinator then assembles those resources, activates those resources, and executes protocols which specify device procedures to invoke.

Components that Utilize Registries

The seven component areas represented in Figure 2 exhibit common characteristics but also provide specialized resources. For example, a registry concept exists within each component to advertise the component's resources and to provide other components access to those resources.[1] Component registries support plug-and-play interaction because they provide the capability for new resources to join a registry on-the-fly while providing the means at any time to remove resources that are no longer available. In essence, each component registry provides a "database" that other components can search in order to determine resource capabilities and requirements. A registry is similar to a CORBA Object Request Broker that utilizes trader and naming services [3], but it contains additional features. Note that component registries for this architecture will be compatible with different categories of middleware so that the architectural principles can remain the same while the architecture continues to utilize emerging object-based software technologies.

Self-Identifying Components

The resources of each component make themselves available through the component's registry by identifying themselves and their capabilities to the registries of other components. For security reasons, the objects that represent newly added resources will have a qualified identification through authentication mechanisms. Each object will support two critical methods: (1) a method to report what inputs (or methods) the object can support and (2) a method to report what outputs (or invocations) the object can produce.

Coordinators that Execute Protocols

The primary purpose of the backplane is to identify resources, activate those resources, and connect them to one another according to some plan. The backplane coordinator object is the means to accomplish this task. Normally, a coordinator begins life when invoked by a user or another protocol, but at startup the backplane must contain a simple registry that invokes coordinators in a manner analogous to a bootstrap loader. Note that a coordinator has no existence without a protocol.

Proposed Standards to Support within this Architecture

To realize this plug-and-play telemedicine device architecture, Sandia plans to draw on the work of a number of standards bodies both inside and outside of the medical community. These include the following:

- IEEE 1073 (Medical Information Bus) [4] – This committee, in conjunction with the VITAL community of CEN, leads the way in the area of standard medical device communications. The VITAL community is performing work that is extremely useful to telemedicine as they define the data dictionary needed for medical device applications as well as an encoding scheme for this data. These VITAL efforts become more powerful in conjunction with the device command and data transport structures defined by IEEE 1073.
- IEEE 1451 ("Smart Sensors") [5] – This work comes from the process control community and has as its centerpiece a sensor architecture that permits plug-and-play operation in distributed networks. This standard's "Electronic Data Sheets" (specifications embedded within the sensors that permit them to report their capabilities to a host) and approach to cleanly partitioning the design of smart sensors serves as a good model for creating plug-and-play devices for telemedicine.

[1] A component registry has elements of a factory design pattern because it can instantiate objects representing a fixed set of resources upon request.

- Due to its open approach, the Common Data Security Architecture (CDSA) [6] advanced by Intel is being studied as a candidate for cryptographic security services. Because the proposed architecture will be initially rendered using CORBA, CORBAmed's Healthcare Resource Access Control (HRAC) facility [7] is being considered for access control functionality.
- Health Level 7 [8] and CORBAmed's Clinical Observations Access Service (COAS) [7] currently appear to provide the best open models for patient record exchange.
- For local communications, IEEE 1394 (also known as "Firewire") [9] holds promise, as do other infrared and radio-frequency wireless efforts. Note that these standards are evolving and will require some time before realizing significant market share.

Incorporation of Information Surety

One of the implicit notions in current security approaches is that one can define the boundary of a system and therefore set up a defensive perimeter around this boundary. When the components that make up "the device" become distributed across a network, a fundamentally different security model is needed. Security issues associated with this distributed approach are addressed in [10].

Conclusions

Most telemedicine systems are custom-designed and do not, in their current implementation, interoperate with other commercial offerings. Users are limited to a set of functionality that a single vendor provides and must often pay high prices to obtain this functionality, since vendors in this marketplace must deliver entire systems in order to compete. Appending new functionality to these systems is an expensive proposition because it suggests additional research and development on the part of the vendor. The only alternative for the user is to purchase a system from a different company that provides the additional required features as part of its functional set. In this case, it is highly unlikely that the second system will talk to the first system.

Health information systems of the future will be highly distributed and mass-networked. In order to accommodate this future while decreasing the costs of telemedicine systems, new componentized telemedicine system architectures are necessary that utilize best-of-breed technologies while incorporating mechanisms for distributed processing. This paper described an object-oriented, plug-and-play architecture for telemedicine that will allow functional components to be integrated together until all of the desired system functionality, and no more, is obtained. To this end, the architecture will support standards for component interoperability so that functionality from different vendors can be integrated onto the same care platform. In addition, the architecture will utilize standards for exchange of medical information that, with the advent of appropriate security technology, will allow these systems to interact with electronic patient records stored in hospital information networks.

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Rick Craft is a Senior Member of the Technical Staff at Sandia National Laboratories, Albuquerque, NM, where he has worked for 14 years. For the majority of this time, Rick has analyzed and designed information systems, concentrating for the last five years on information security techniques as well as helping system designers identify and secure system vulnerabilities. Rick holds a B.S. and M.S. in Electrical Engineering from the Georgia Institute of Technology.

Ray Parks is a Senior Member of the Technical Staff at Sandia National Laboratories, Albuquerque, NM. He received a B.S. in Engineering from the U.S. Air Force Academy in 1978. Ray's technical interests include distributed systems assurance, information warfare, object technology, middleware, intranets, and extranets. His current work focuses on red-teaming, vulnerability analysis, and the incorporation of security and surety into distributed systems.

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